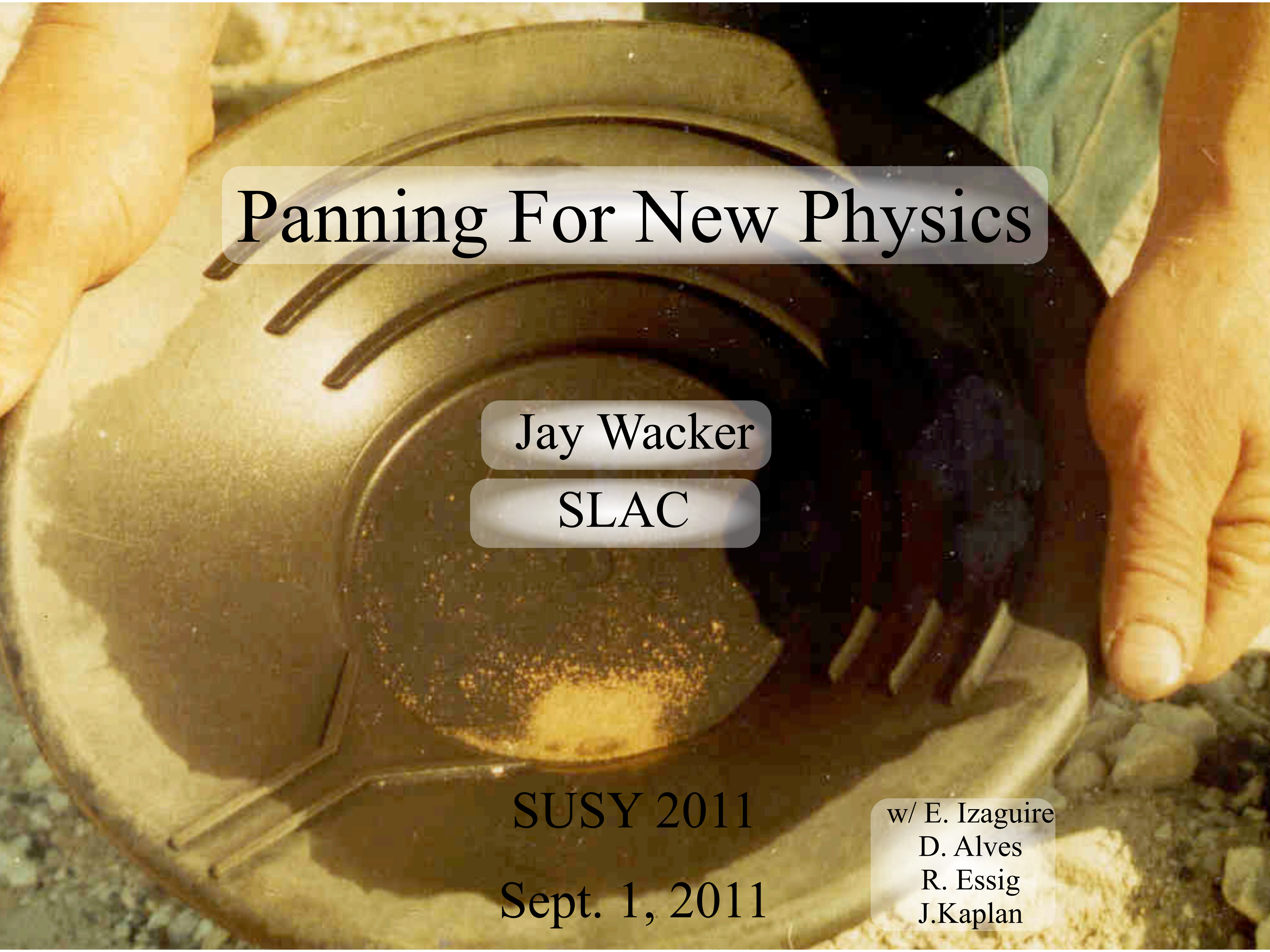


# Panning For New Physics


Jay Wacker

SLAC


SUSY 2011

Sept. 1, 2011


w/ E. Izaguire
D. Alves
R. Essig
J.Kaplan

# Fermilab 1999

SUSY99 was my first physics conference

Working on CDF putting together the COT

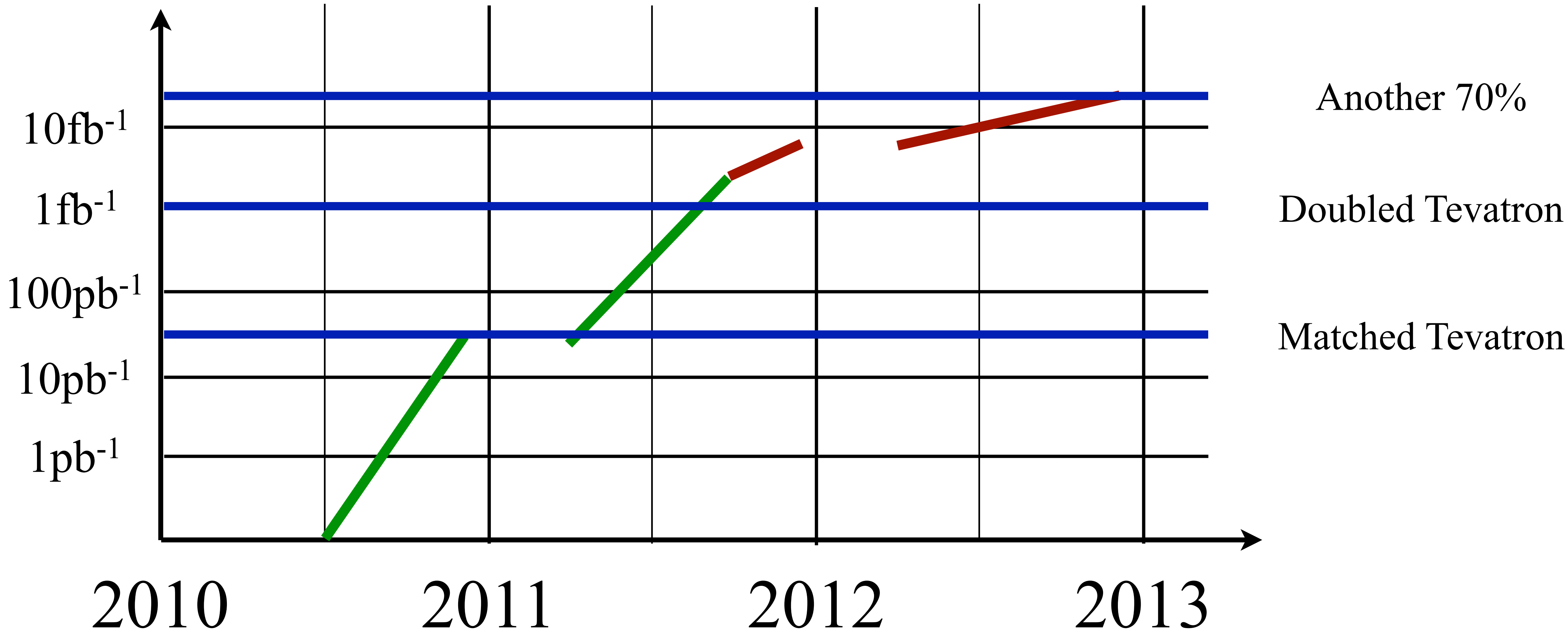
Great Times & Really Exciting!

12 Years Later:

# 2 Years into the LHC

How are we doing?

Gain in Mass Reach




Fastest pace change in my physics career!

# The Searches at the LHC
# Seem to be going great

More searches being done

(Including many new ones)

Searches being done very quickly

Searches being designed with less model dependence

<u>Discuss how we should evaluate performance</u>

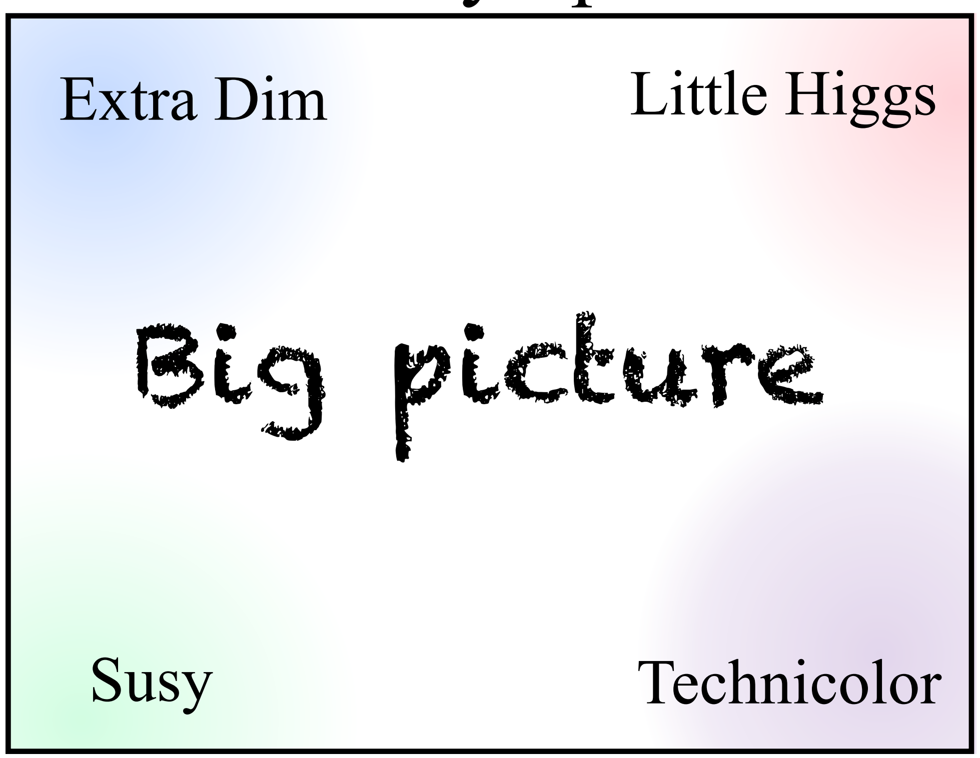
– Review of Simplified Models

– Efficacy

# Should be Discovery Time!

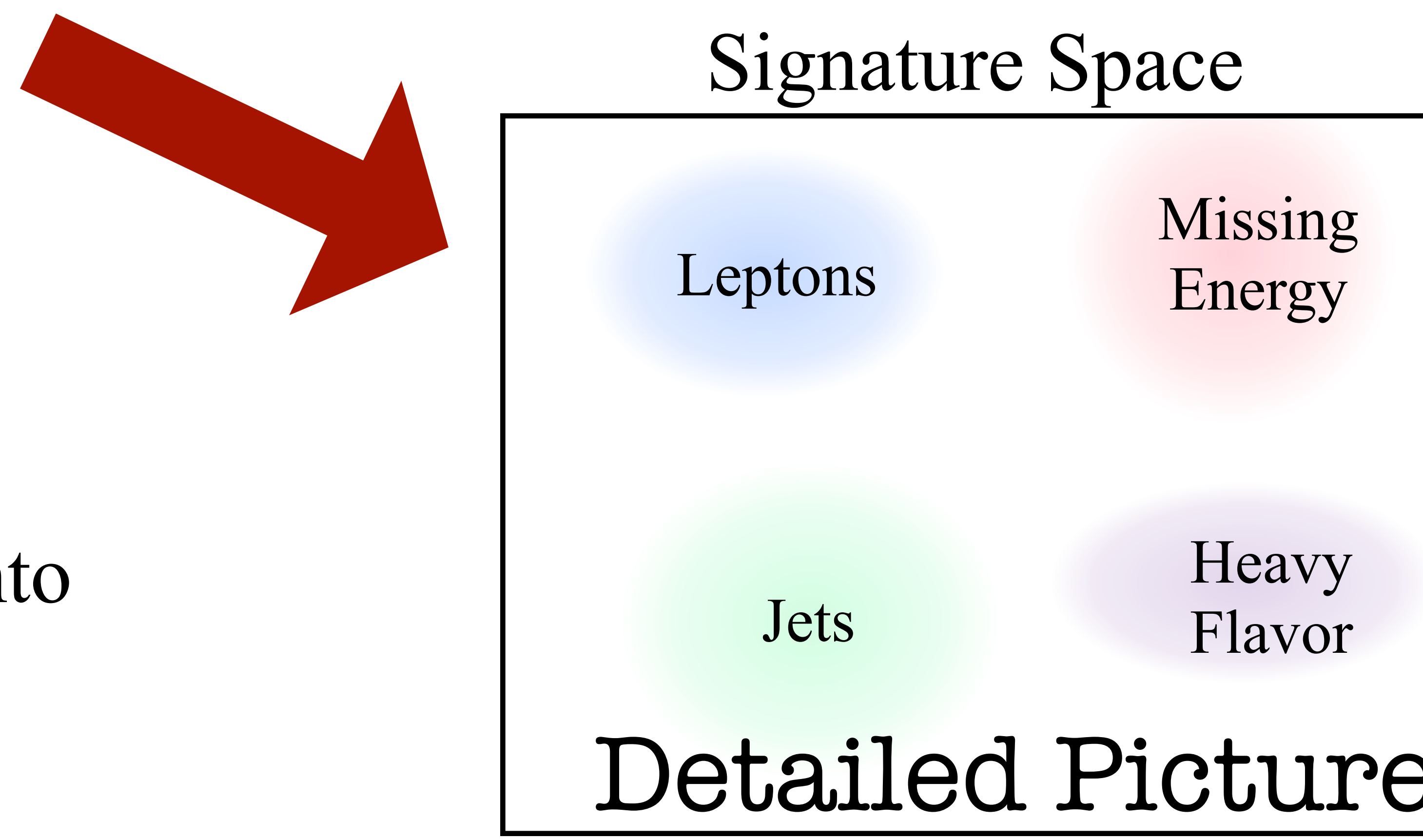
## How to make sure that no stone is unturned?

Theory Space




Constructing Signature Space
from Theory Space
not easy/efficient

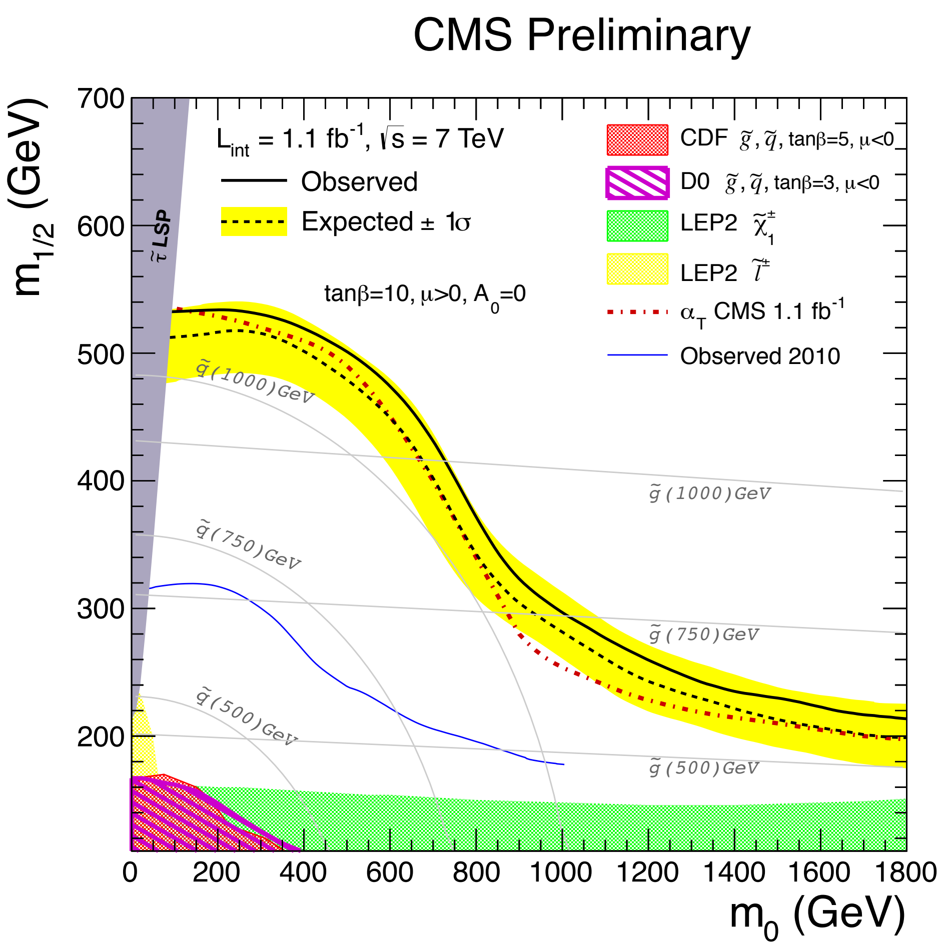
Signature Space




Need axes for
Theory Space to map into
Signature Space

# Problem with Model Dependent Search Design

mSugra: $m_{\frac{1}{2}}, m_0^2, A_0, B_\mu, \mu$




A great search for jets + MET

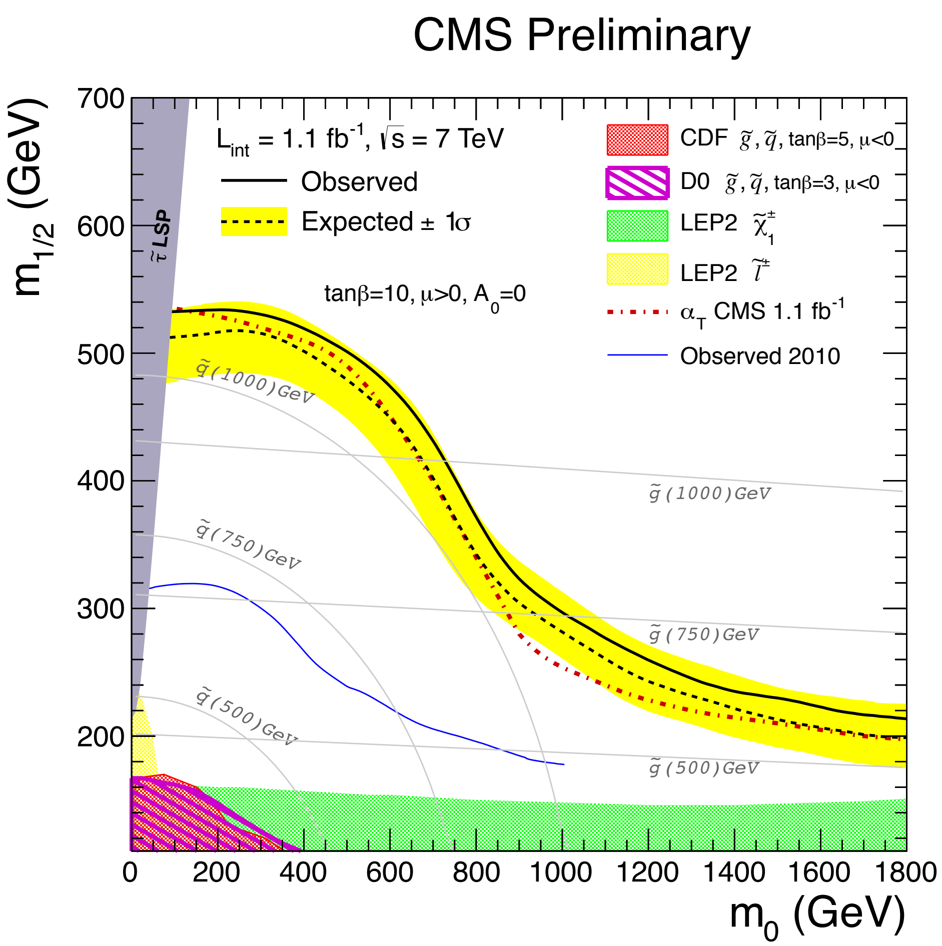
$$pp \longrightarrow \tilde{g}\tilde{g}$$

$$\tilde{g} \longrightarrow q\bar{q}\tilde{W} \quad + \ldots$$

$$\tilde{W} \longrightarrow W\tilde{B}$$

# Problem with Model Dependent Search Design

mSugra: $m_{\frac{1}{2}}, m_0^2, A_0, B_\mu, \mu$




A great search for jets + MET

$$pp \longrightarrow \tilde{g}\tilde{g}$$

$$\tilde{g} \longrightarrow q\bar{q}\tilde{W} \quad + \ldots$$

$$\tilde{W} \longrightarrow W\tilde{B}$$

What happens if $m_{h^0} = 140 \text{ GeV}$ ?

Squark masses need to be ~1000 TeV

Be a peculiar corner of mSugra (if it exists)

Every mSugra scan would be useless, how do we interpret?

Would have to determine which mSugra features are generic?

# Simplified Models

## Limits of specific theories

Only keep particles and couplings relevant for searches

Still a full Lagrangian description

## Removes superfluous model parameters

Masses, Cross Sections, Branching Ratios (*e.g.* MARMOSET)

Add in relevant modification to models (*e.g.* singlets)

## Not fully model independent, but greatly reduce model dependence

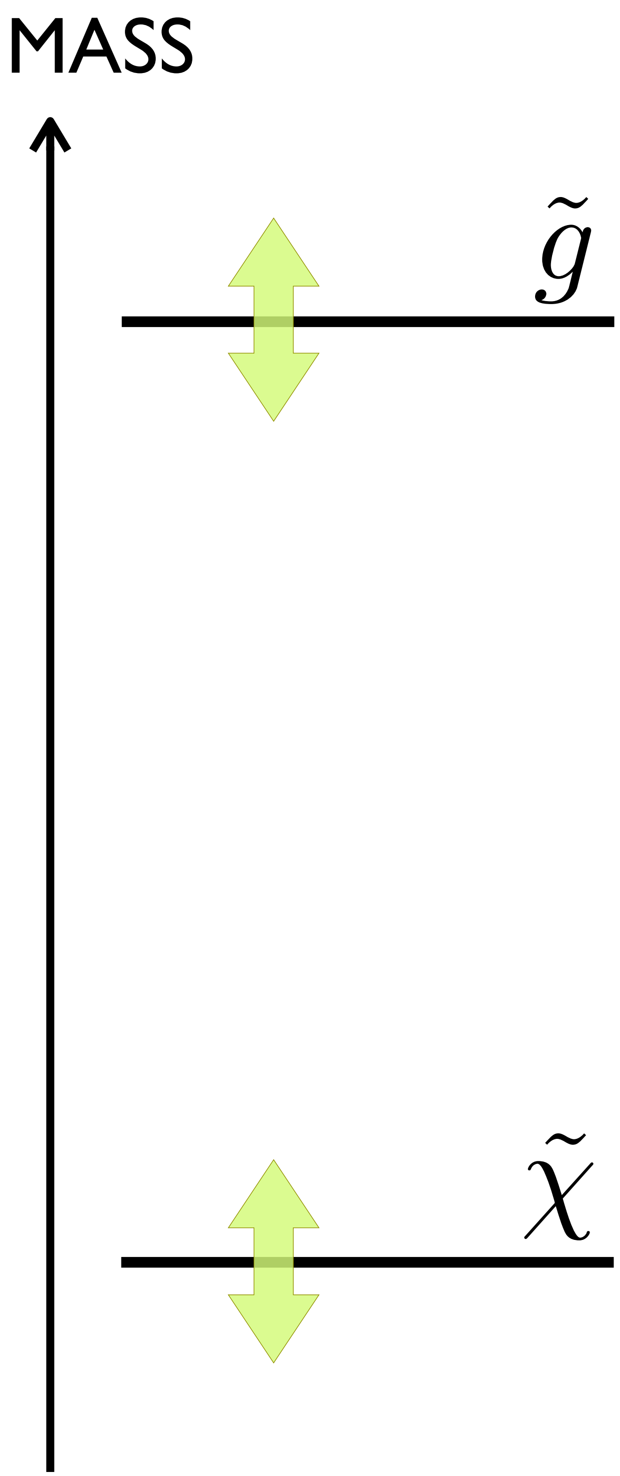
## Captures specific models

Including ones that aren't explicitly proposed

Easy to notice & explore kinematic limits

# Simplified Models

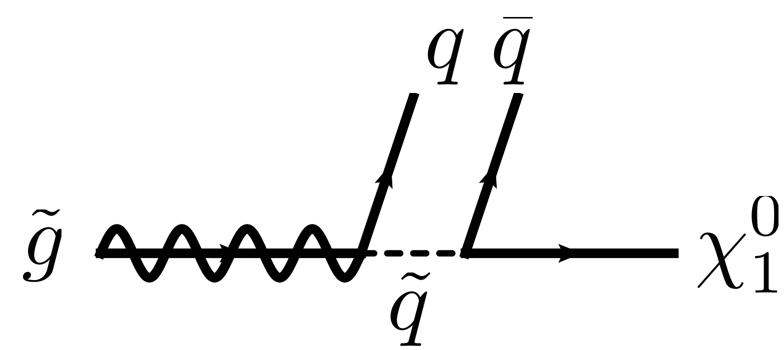
Direct Decays




color octet majorana fermion ("Gluino")

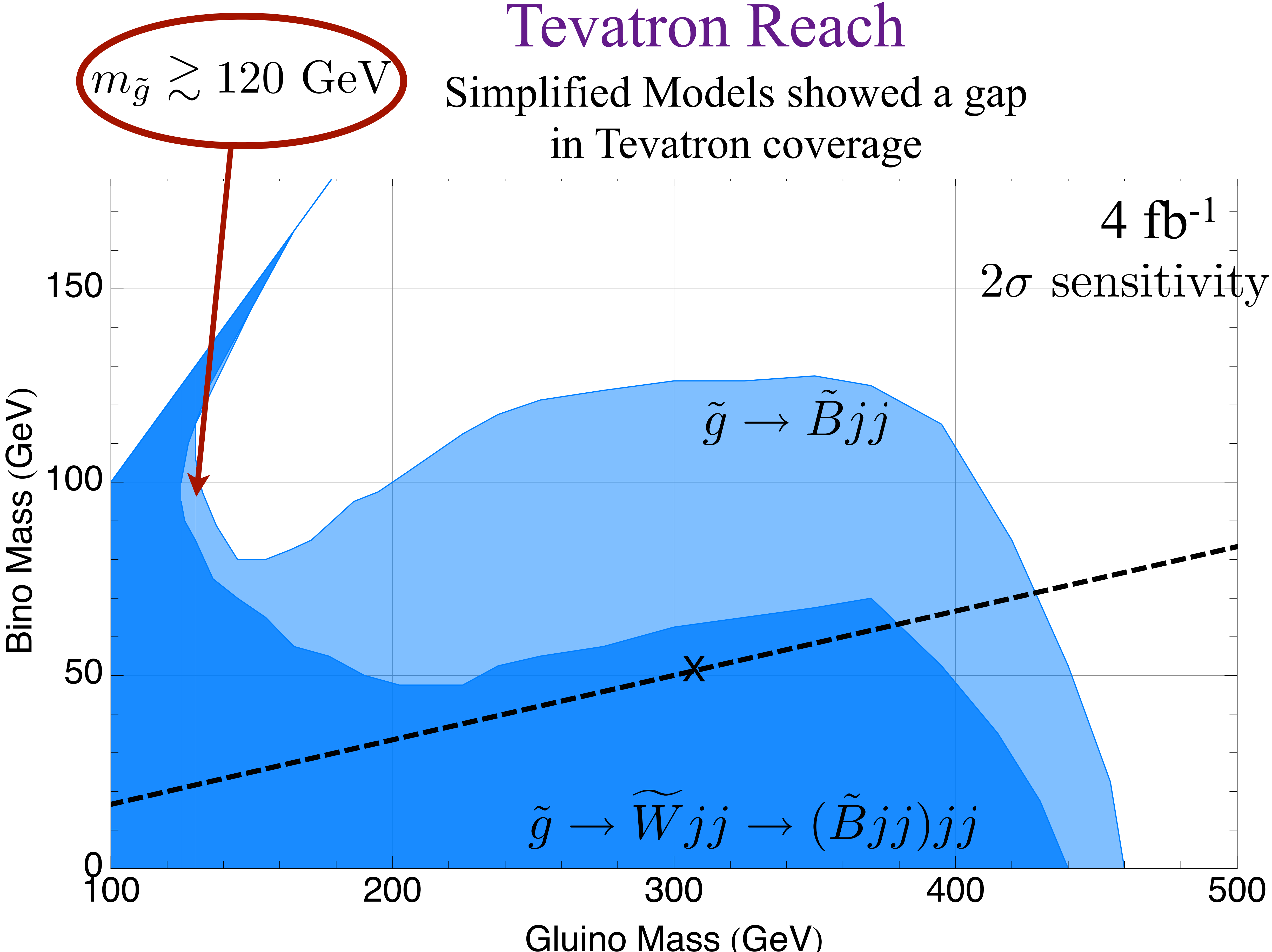
neutral majorana fermion ("LSP")

**THREE-BODY**



# Tevatron Reach

Simplified Models showed a gap
in Tevatron coverage




Alwall, Le, Lisanti, Wacker 2008

Important to keep the cross section free

All searches at LHC are model dependent

Easy to dilute signal with small branching ratios

Rate ~ $\sigma \times \left(\mathrm{Br}(\tilde{g} \to X)\right)^2$

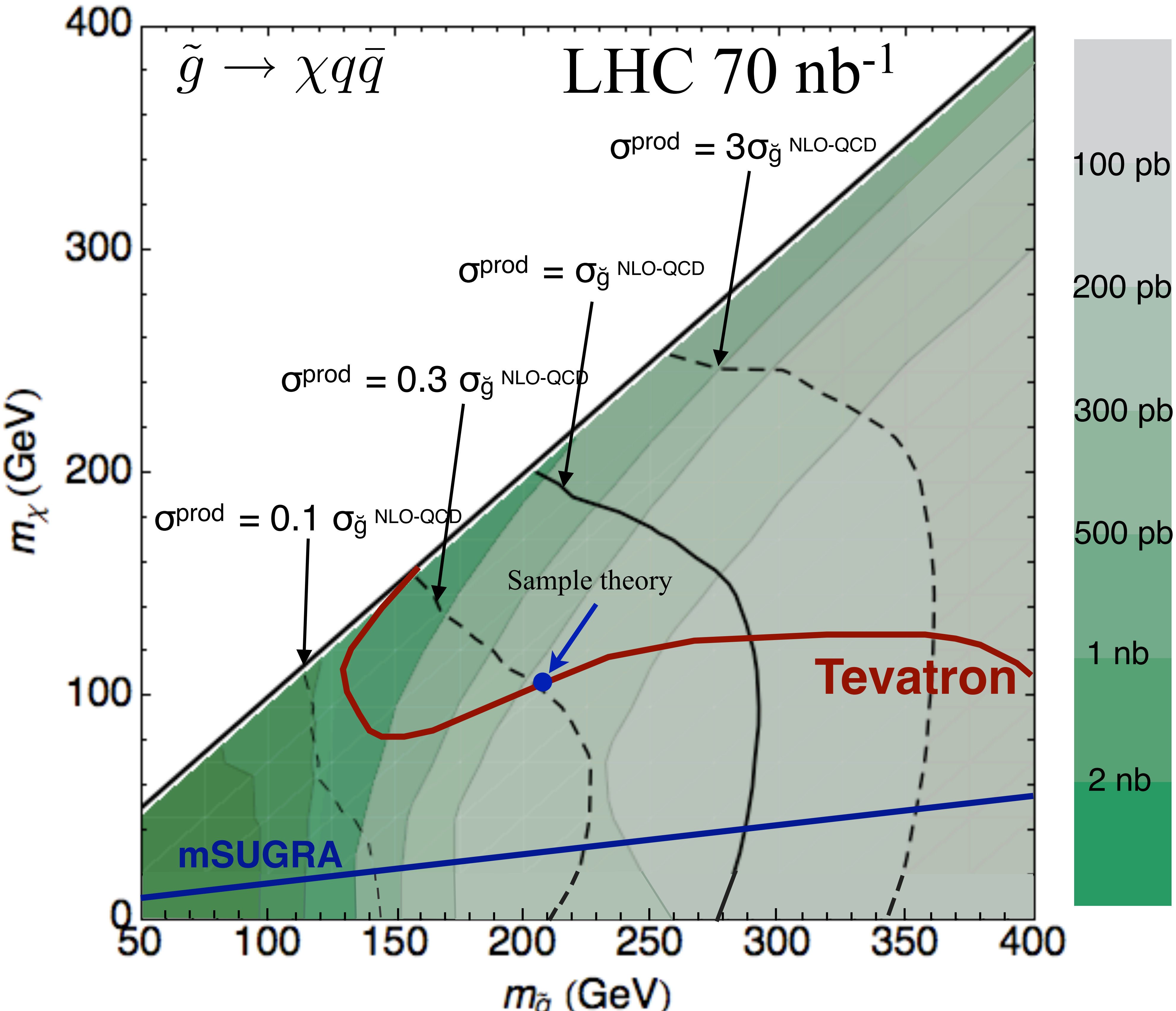
If $\mathrm{Br}(\tilde{g} \to X) \sim \frac{1}{3}$

the rate drops by an order of magnitude

Dropping S/B by an order of magnitude
dramatically changes discovery prospects

# Putting it all together

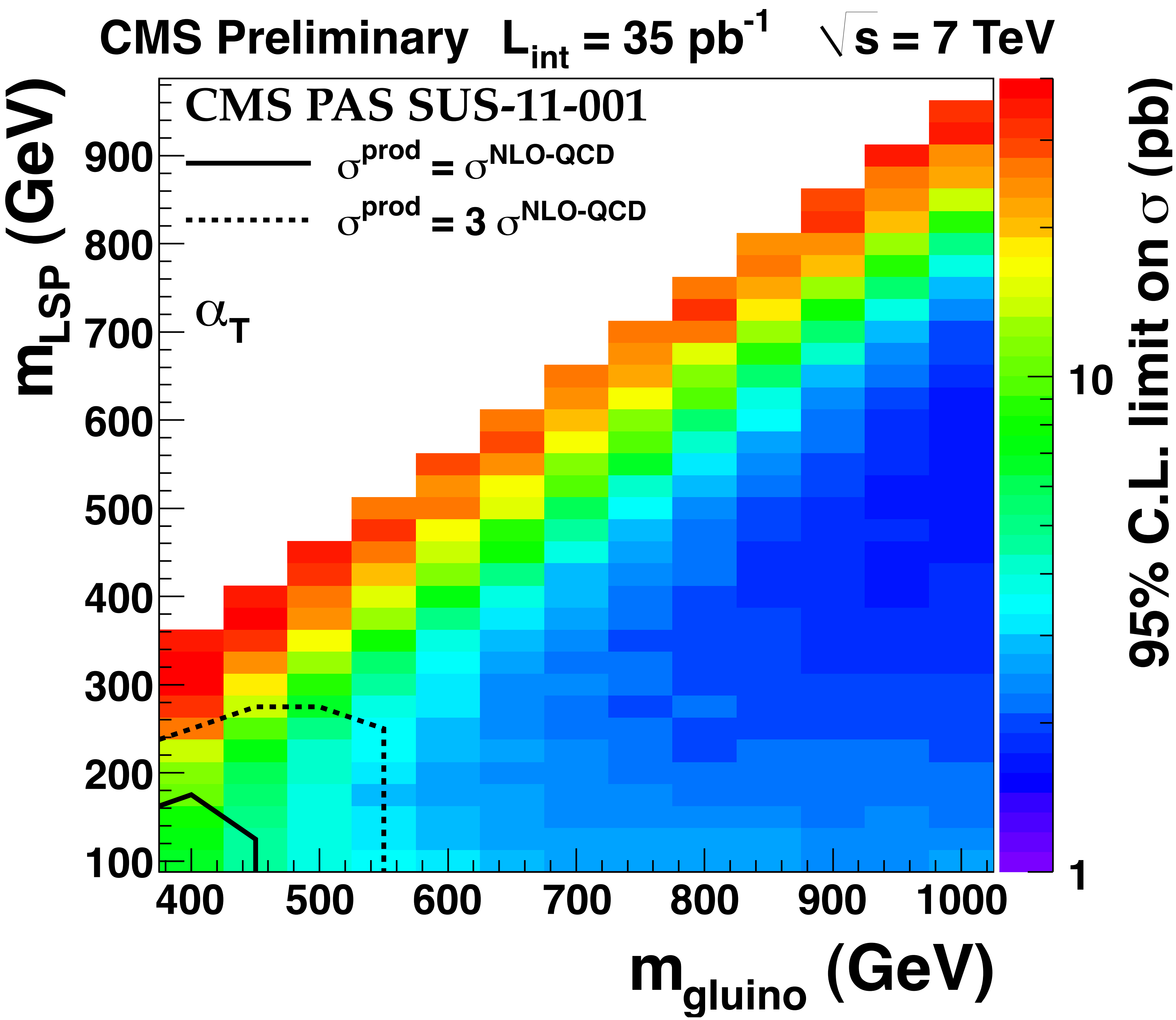
## There could have been discoveries!



# Much easier to interpret!

$m_{\tilde{g}} = 400\ \mathrm{GeV}$ $m_{\chi^0} = 50\ \mathrm{GeV}$ $\sigma \times \mathrm{Br} \leq 8\ \mathrm{pb}$

$m_{\tilde{g}} = 400\ \mathrm{GeV}$ $m_{\chi^0} = 370\ \mathrm{GeV}$ $\sigma \times \mathrm{Br} \leq 30\ \mathrm{pb}$



# How to Determine If the Searches are Good Enough

Concept of "Efficacy"

Take your favorite benchmark model

$$\mathcal{E} = \frac{\sigma^{\text{actual search}}_{\text{expected lim.}}}{\sigma^{\text{best possible}}_{\text{expected lim.}}}$$

Doing well if $\mathcal{E} \simeq 1$

# Efficacy

It only asks how effective is a search *relative* to how well it is possible to do

Even if

$$\sigma^{\text{best possible}}_{\text{estimated lim}} \gg \sigma_{\text{expected}}$$

or $\sigma^{\text{best possible}}_{\text{estimated lim}} \ll \sigma_{\text{expected}}$

searches should be improved

Eliminates some model prejudice

Not easy to determine $\sigma^{\text{best possible}}_{\text{estimated lim}}$

# Why it Matters?

3 Phases of a Search

Systematic errors exist $\epsilon \sim 20\% \rightarrow 100\%$

$$N_{\text{signal lim}} \simeq 1 \oplus N_{\text{bg}}^{\frac{1}{2}} \oplus \epsilon\, N_{\text{bg}}$$

$$N_{\text{signal}} \propto \mathcal{L}\, \sigma_{\text{signal}} \qquad N_{\text{bg}} = \mathcal{L}\, \sigma_{\text{bg}}$$

| | | |
|---|---|---|
| Rate Limited | $N_{\text{bg}} \lesssim 1$ | $\sigma_{\text{lim}} \propto \mathcal{L}^{-1}$ |
| Statistics Limited | $1 \lesssim N_{\text{bg}} \lesssim \epsilon^{-1}$ | $\sigma_{\text{lim}} \propto \mathcal{L}^{-\frac{1}{2}}$ |
| Systematics Limited | $N_{\text{bg}} \gtrsim \epsilon^{-1}$ | $\sigma_{\text{lim}} \propto \mathcal{L}^{0}$ |

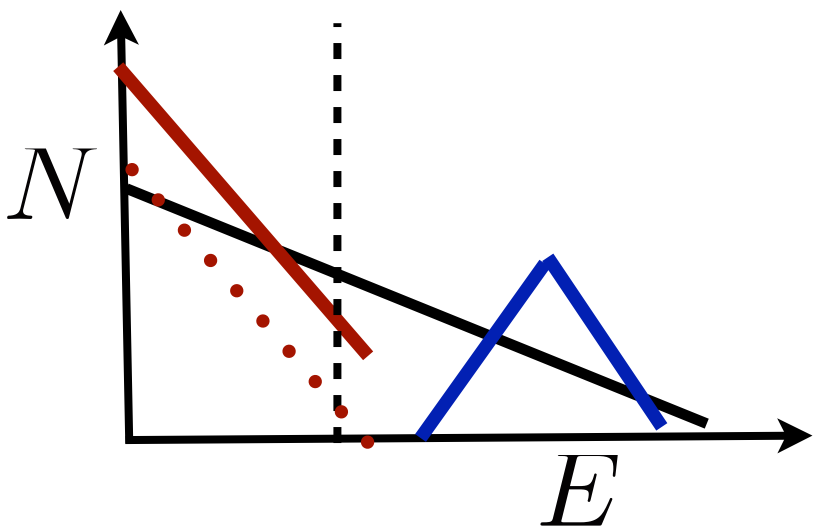
## If a search has poor efficacy

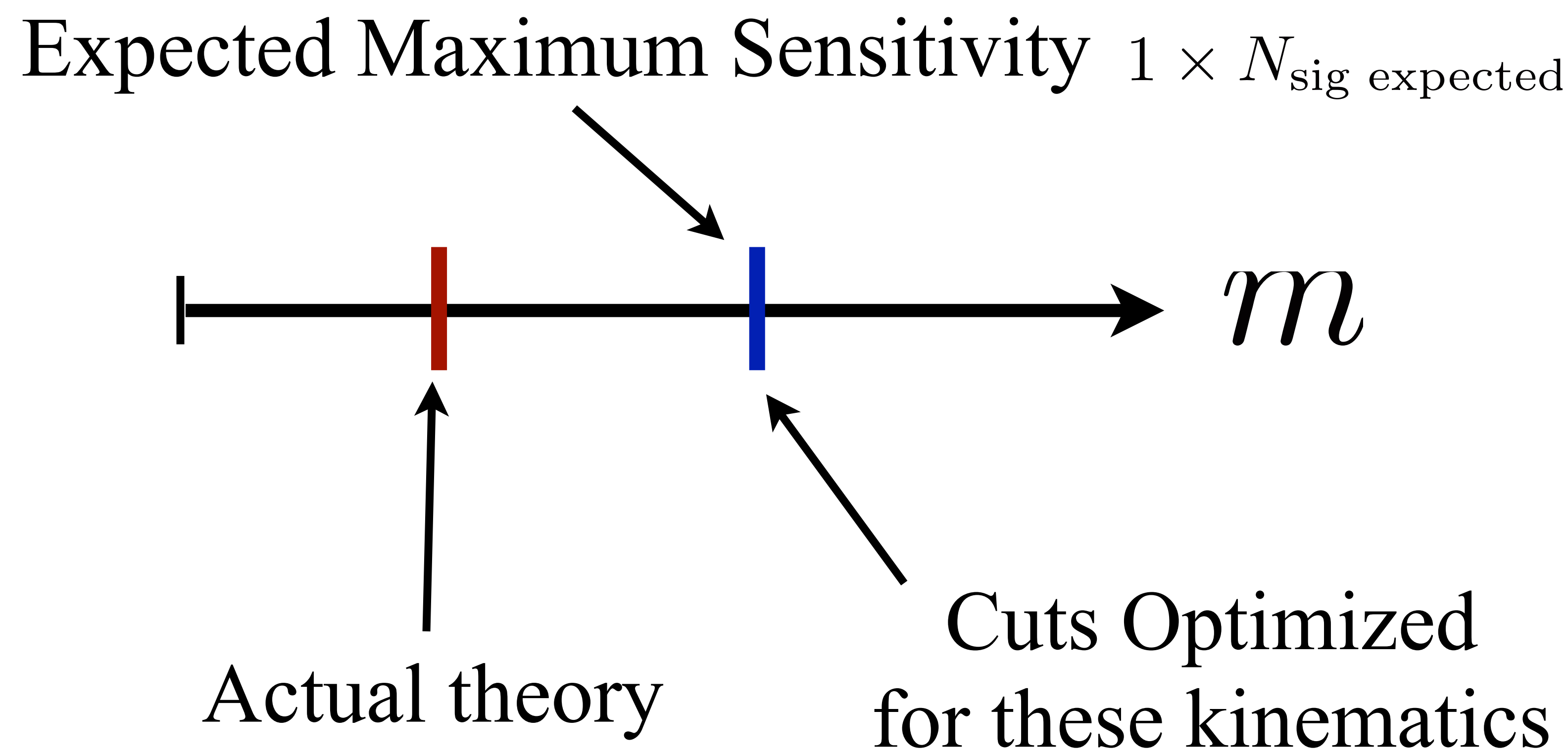
## Takes longer to discover

| | Rate Limited | Statistics Limited | Systematics Limited |
|---|---|---|---|
| $\frac{\mathcal{L}_{\text{Needed}}}{\mathcal{L}_{\text{min}}}$ | $\mathcal{E}$ | $\mathcal{E}^2$ | $\to \infty$ |
| $\mathcal{E} = 5$ | 5 times longer | 25 times longer | Prematurely Systematically limited |
| $\mathcal{E} = 2$ | 2 times longer | 4 times longer | Possibly Prematurely Systematically limited |

In practice, usually search regions are tweaked
to prevent systematics from dominating

# How Blind Spots Develop




$$N_{\text{signal}} = \mathcal{L}\, \sigma_{\text{signal}}\, \text{Br}\, \epsilon_{\text{eff}}$$

$$\sigma_{\text{actual}} \ll \sigma_{\text{expected}}$$

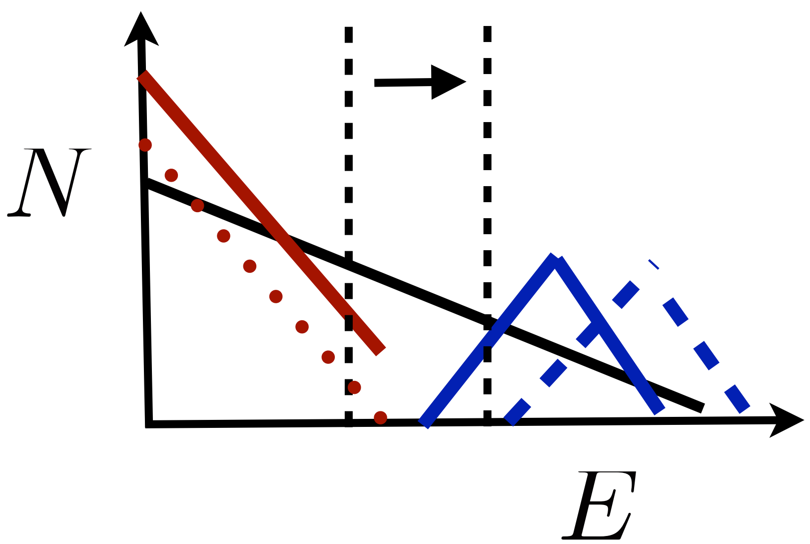
$$\text{Br}_{\text{actual}} \ll \text{Br}_{\text{expected}}$$

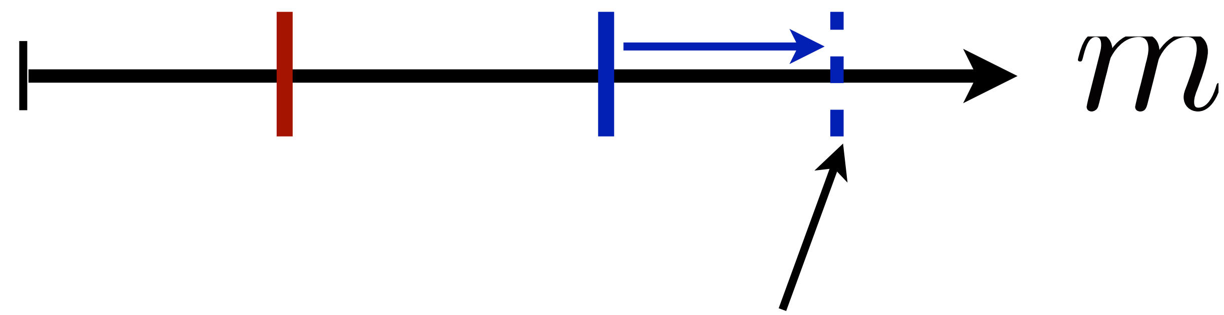
$$\epsilon_{\text{eff actual}} \ll \epsilon_{\text{eff expected}}$$

# How Blind Spots Develop

At higher luminosity, cuts change

Triggers change, Kinematics change, Systematics change




Cuts Re-optimized for these kinematics

(expect searches to be systematically limited)

New kinematics more different than before from true theory

Efficiencies drop

$$\epsilon_{\text{eff actual}} \ll \epsilon_{\text{eff expected}} \lesssim \epsilon_{\text{eff new expected}}$$

Note CMS plot didn’t go beneath 400 GeV

# Designing Search Regions

Want the Efficacy bounded for all masses
and decay topologies

Keep $\mathcal{E} \leq \mathcal{E}_{\mathrm{crit}}$ for all theories

Need a set of search regions
when combined has universal coverage

$$\mathcal{E}(\mathcal{M},\mathcal{S}) = \frac{\sigma_{\mathrm{lim}}(\mathcal{M},\mathcal{S})}{\sigma_{\mathrm{lim}}^{\mathrm{best}}(\mathcal{M})} \geq 1$$

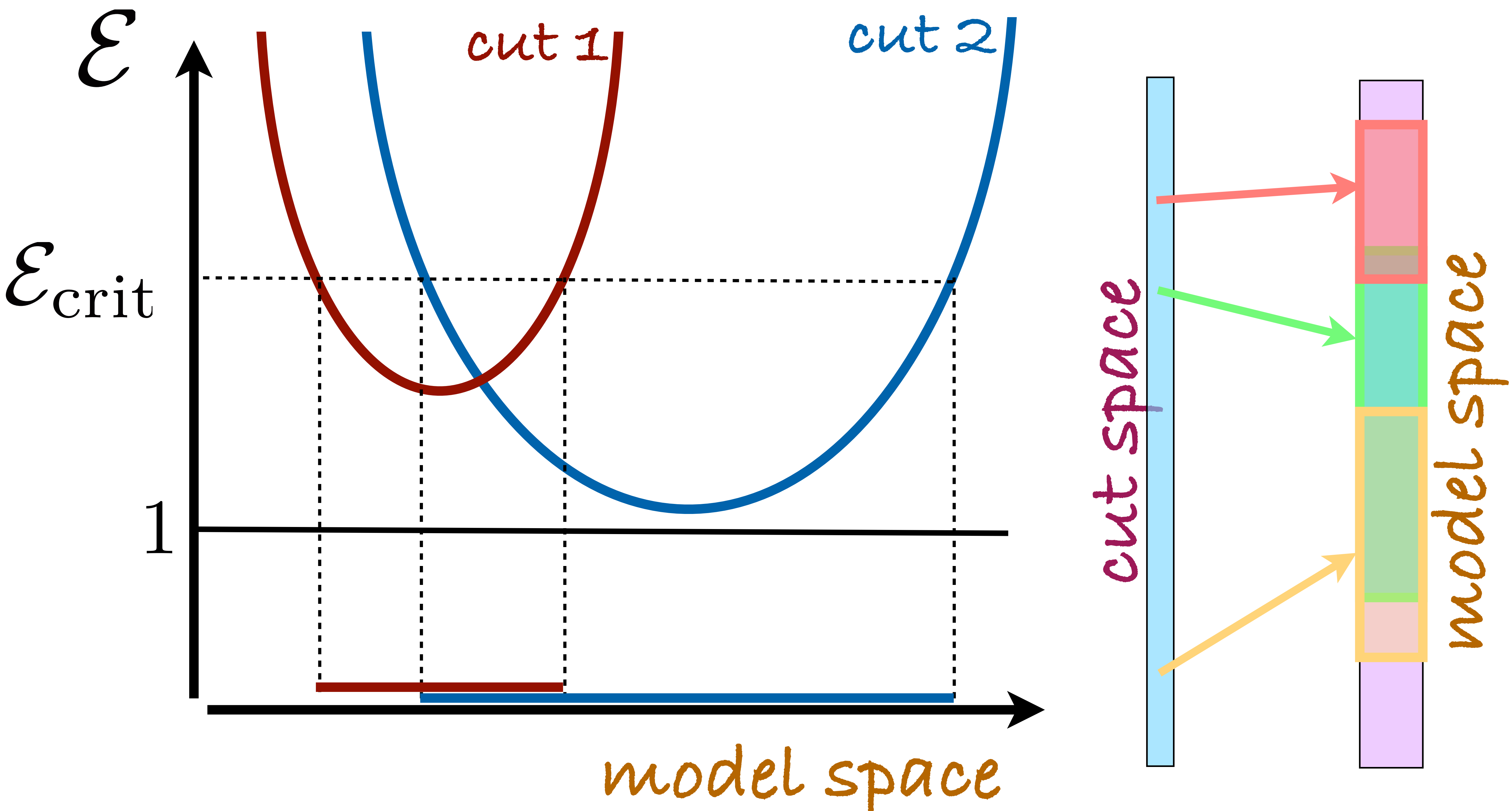
$\mathcal{M} =$ Model

$\mathcal{S} =$ Search Region

Number of search regions depends on desired Efficacy

# Hunting for Optimal Cuts

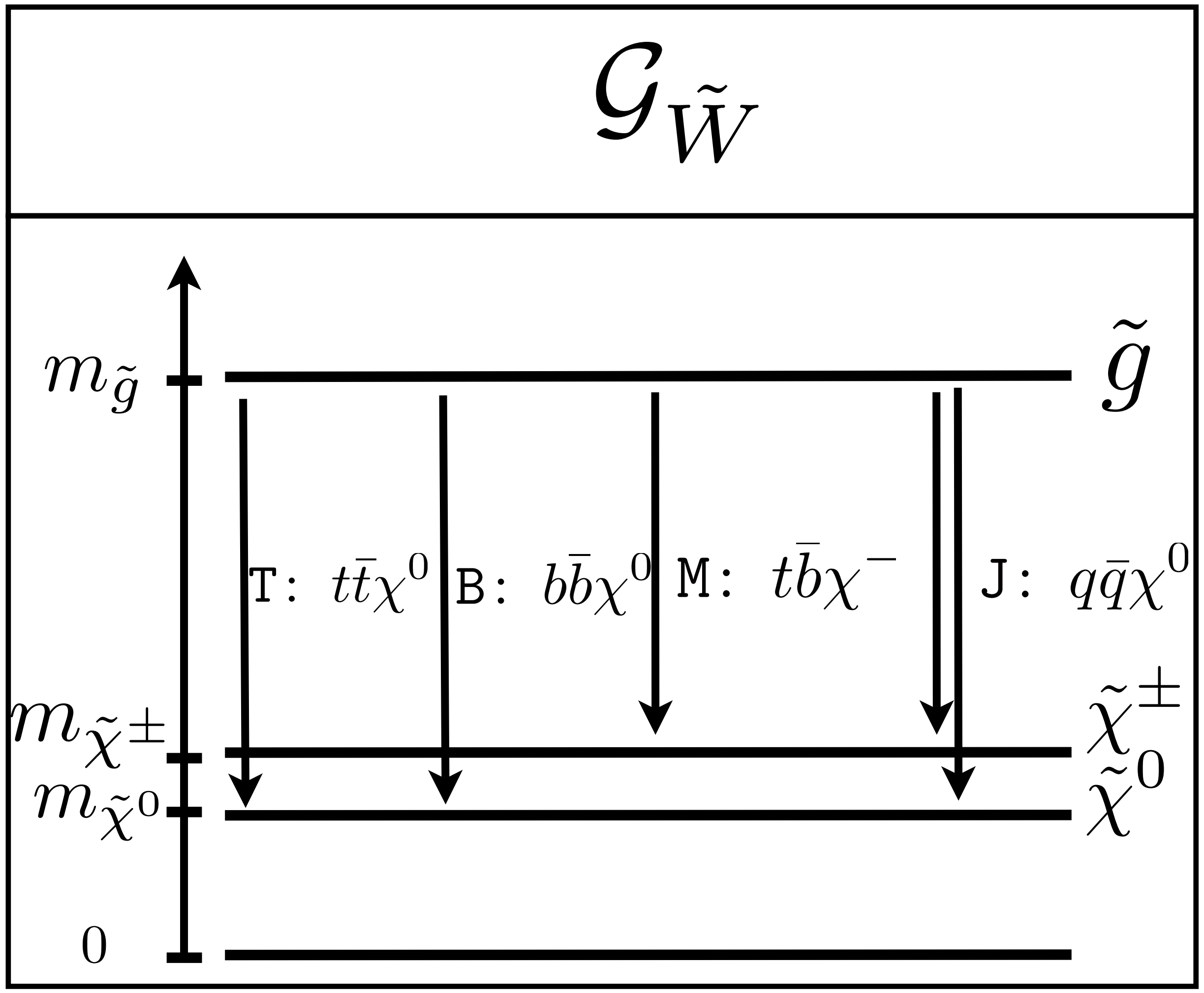
Find the *minimum* set of cuts whose *combined* reach is close to optimal (within a given accuracy) for all models.

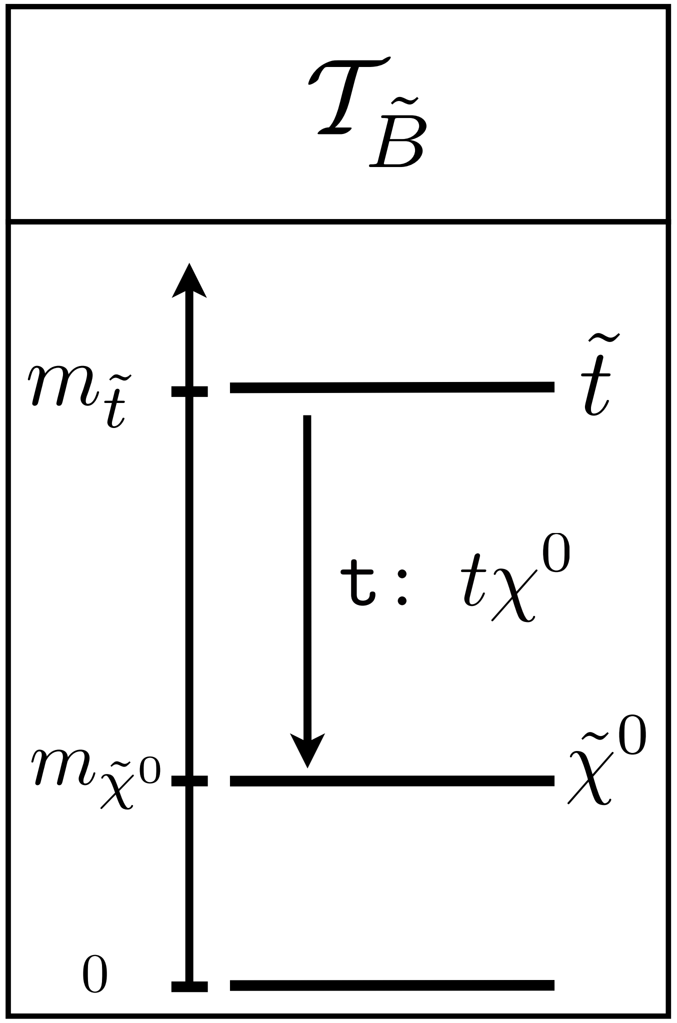


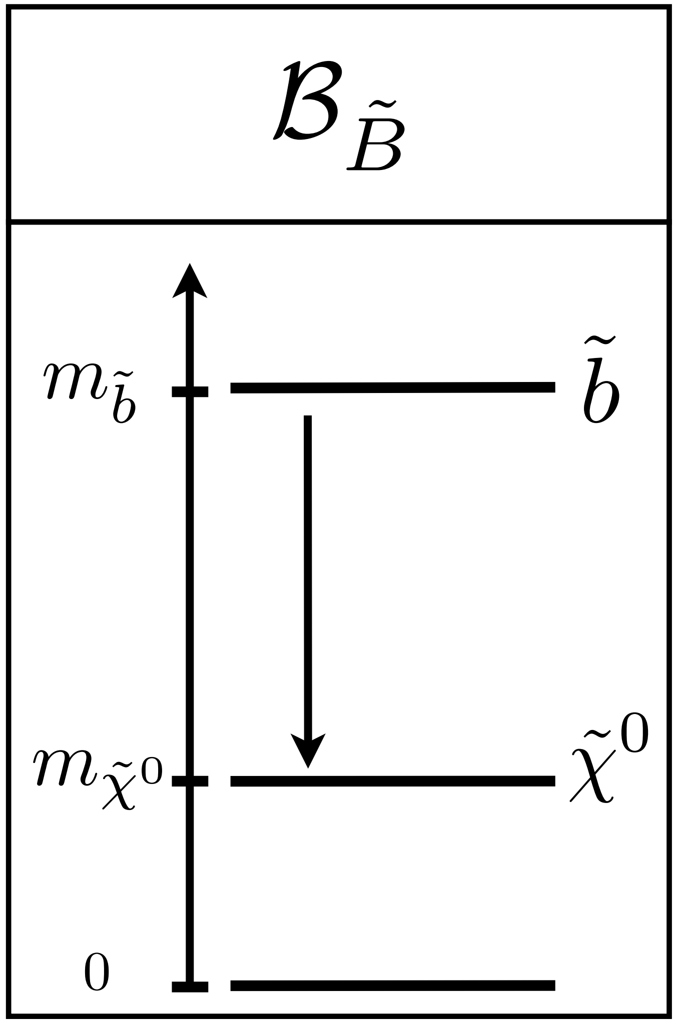
# Case Study: Heavy Flavor Susy Jets+MET

Gluinos

Squarks




10 Topologies

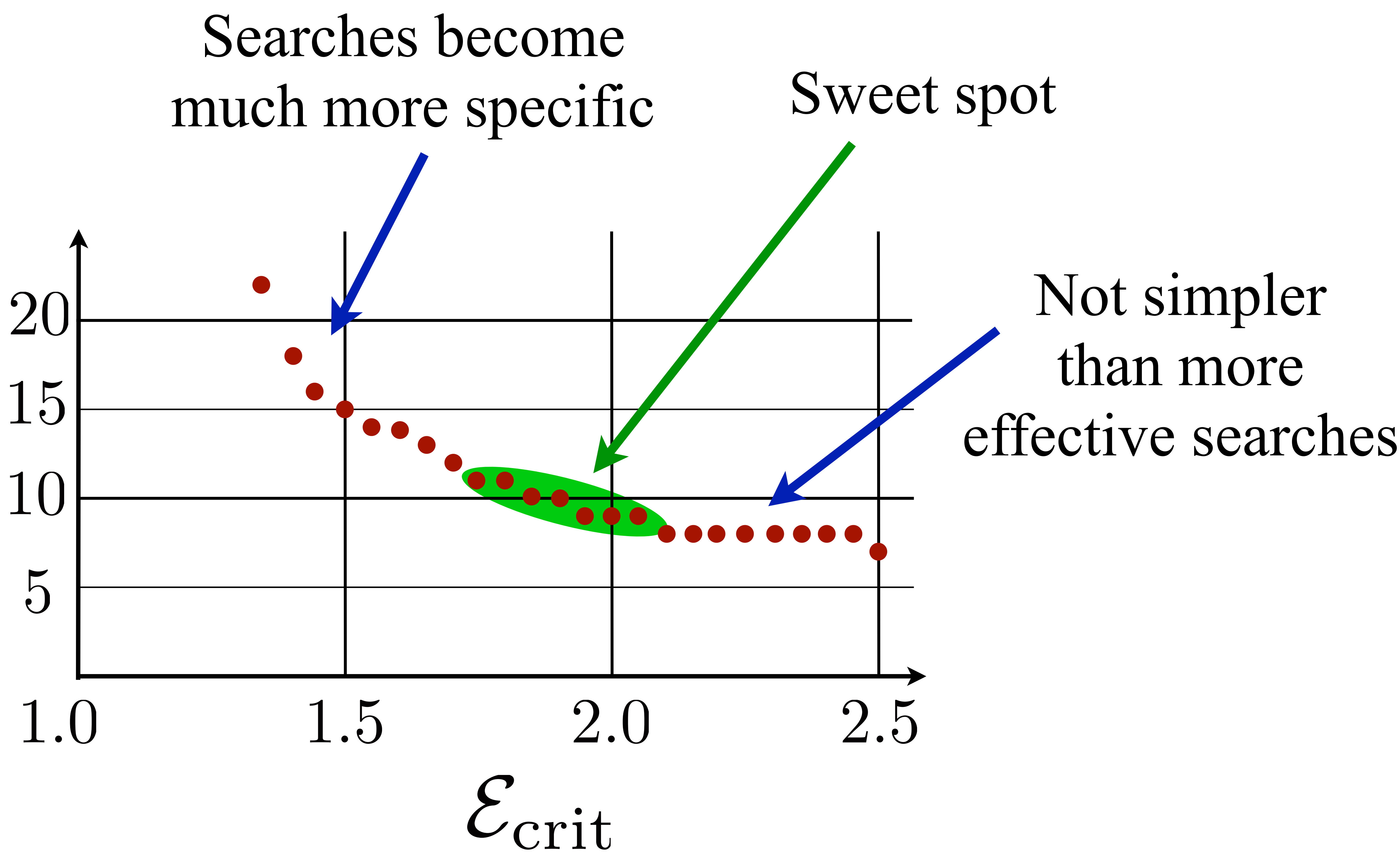
2 Topologies

Have 3 Free Parameters in Each Topology

2 Masses & Cross Section x BR

# How Many Search Regions Necessary?

Design Search Regions for float Efficacy



# What are these searches?

(searches useful for 1/fb to 15/fb)

| | Search Region | $N_j$ | $N_\ell$ | $N_{\mathrm{bjet}}$ | $\not{E}_T$ | $H_T$ |
|---|---|---|---|---|---|---|
| High HT | 1 | $4^+$ | 0 | 0 | 300 | 1000 |
| High MET | 2 | $4^+$ | 0 | 0 | 400 | 500 |
| 1 $b$ Low multiplicity | 3 | $2^+$ | 0 | $1^+$ | 400 | 400 |
| 1 $b$ High HT | 4 | $4^+$ | 0 | $1^+$ | 300 | 800 |
| 1 $b$ High MET | 5 | $4^+$ | 0 | $1^+$ | 400 | 500 |
| 2 $b$ High MET | 6 | $3^+$ | 0 | $2^+$ | 250 | 400 |
| 3 $b$ High MET | 7 | $3^+$ | 0 | $3^+$ | 250 | 600 |
| 3 $b$ Low MET | 8 | $4^+$ | 0 | $3^+$ | 150 | 300 |
| $b$ SSDL | 9 | $2^+$ | SSDL | $1^+$ | 0 | 200 |

2 Normal Light Flavor

4 Normal Heavy Flavor

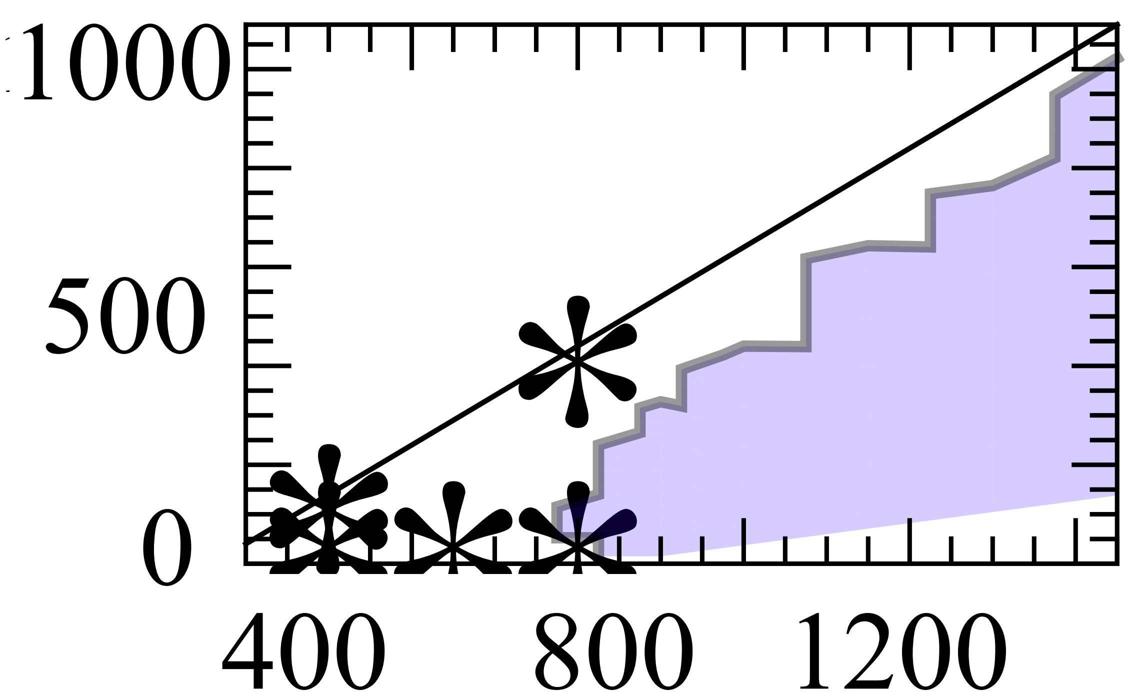
3 Low BG Heavy Flavor

# 4 Tops + MET

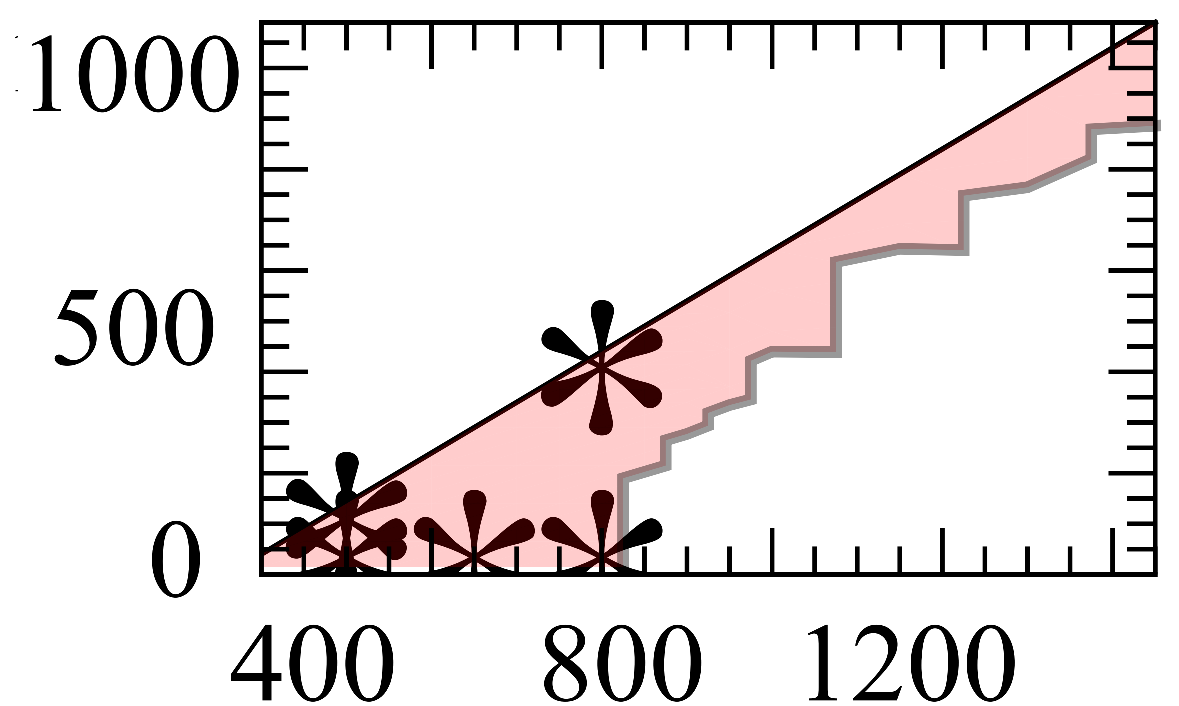
$$\tilde{g}\tilde{g} \to (t\bar{t}\chi^0)(t\bar{t}\chi^0)$$

2 Search Regions Cover Everything at 1 fb$^{-1}$

4 jets, 1 bjet, MET>400




2 jets, 1 bjet, SSDL



# Pretty Fool-Proof

Get all the relevant topologies

Do scans of relevant parameters

Consider all possible searches

Specify how good is good enough

Design a set of searches covering everything

Perform the searches!

Really MC Intensive!

We had 3000+ models with just 12 topologies

# Models Share Broad Similarities

Can optimize over a small subset
and still find the that you need the same 9 searches

60 Benchmark Heavy Flavor Models work

With well-chosen models, you can mindlessly optimize
and not overtune the searches

Full simulation doesn't need to be wasted
on doing extensive scans

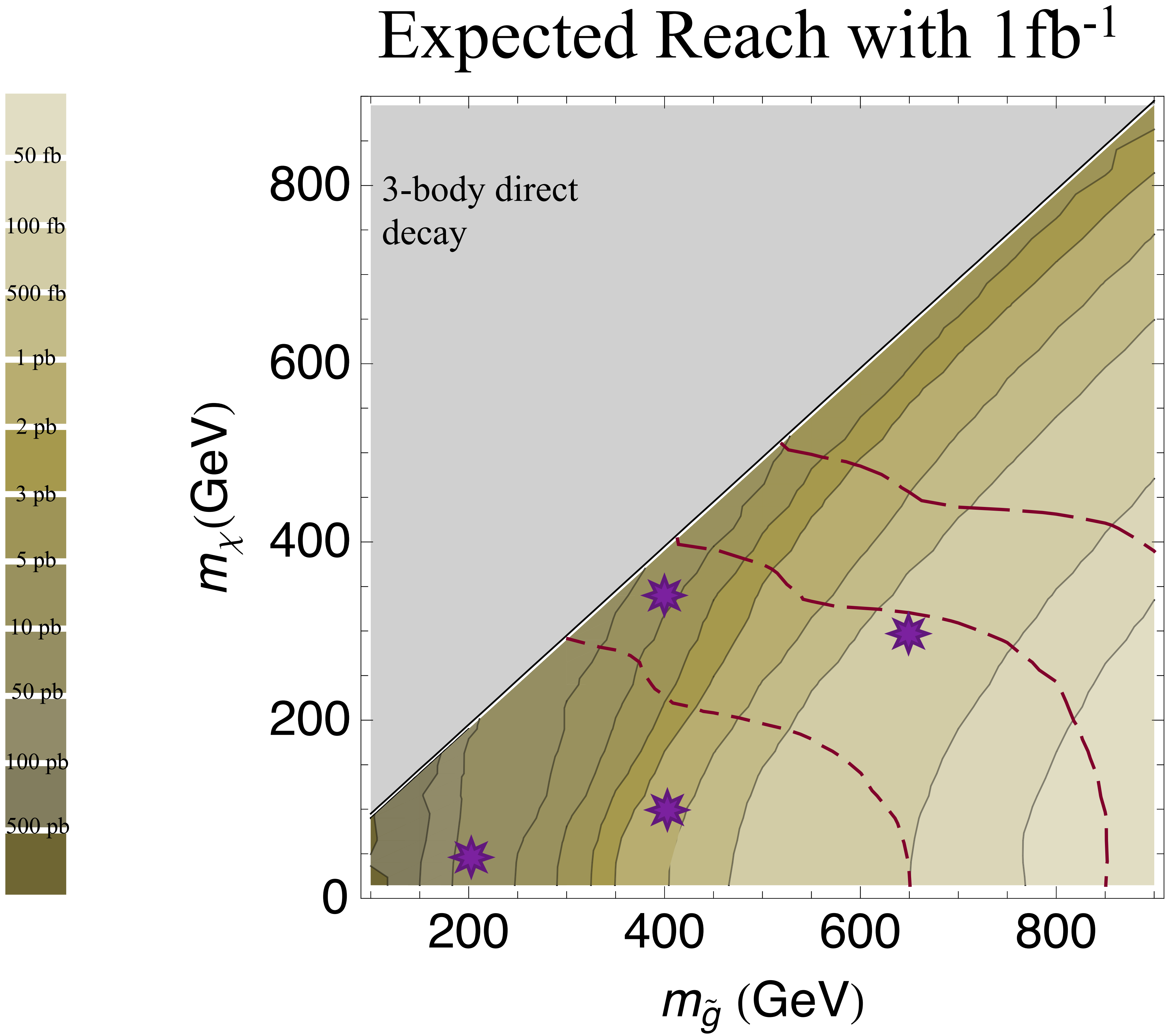
Benchmarks are chosen to be maximally different in Signature Space

Certain combinations of Searches are effective at covering many models

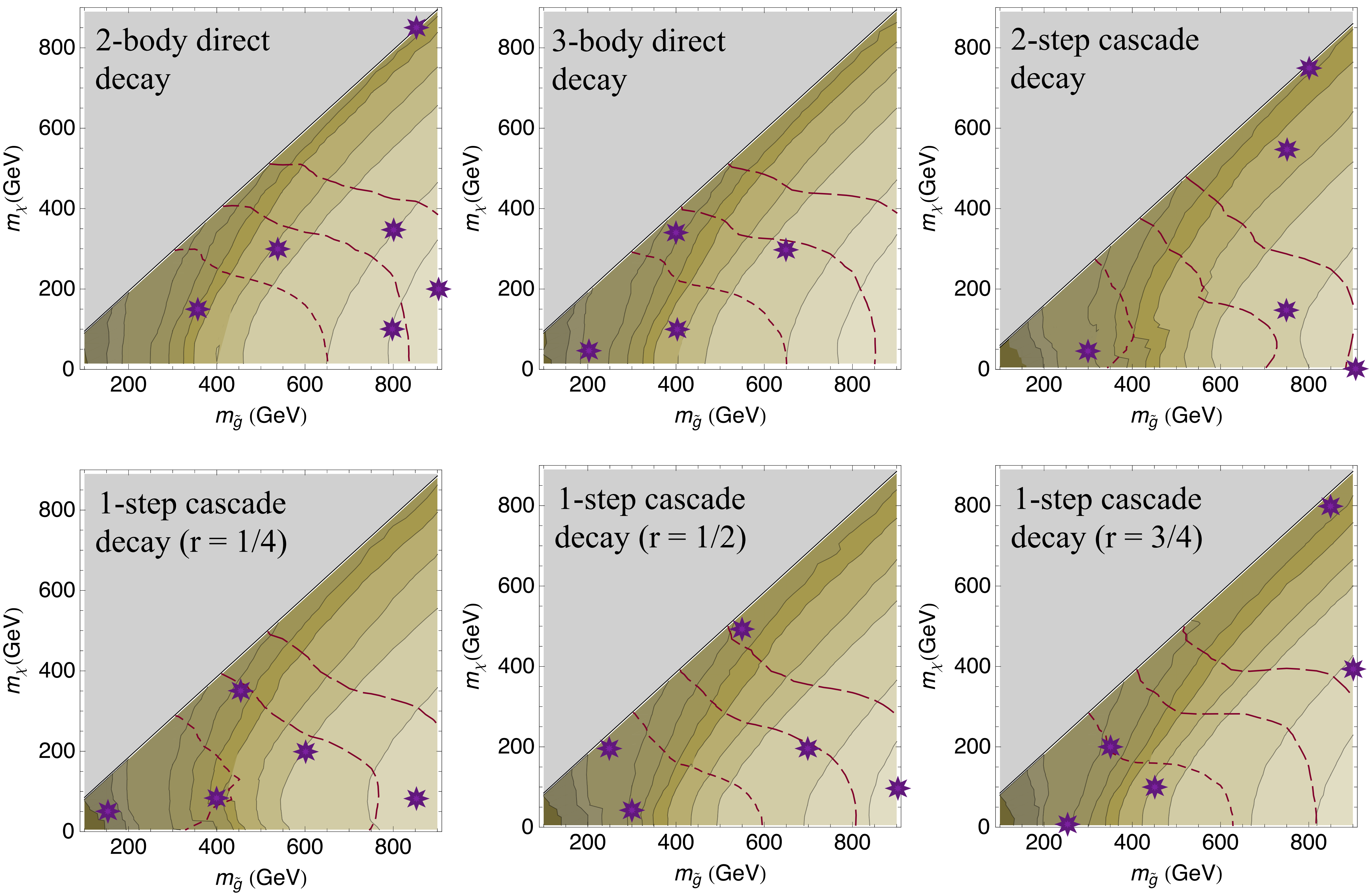
The benchmarks are chosen to identify these combinations

Benchmarks are more reliable to communicate between Theory & Experiment

# Contours of estimated reach for $\sigma(\tilde{g}\tilde{g})\mathrm{Br}^2$



# 30 Light Flavor Benchmarks



# The 30 Light Flavor Benchmarks used by ATLAS

Found that efficacies for light-flavor Jets+Leptons+MET

| | |
|---|---|
| For ~50% | $\mathcal{E} \lesssim 2.0$ |
| For ~30% | $2.0 \lesssim \mathcal{E} \lesssim 5.0$ |
| For ~20% | $\mathcal{E} \gtrsim 5.0$ |

Could regain coverage typically by tweaking cuts to pull signal from background

Modified a trigger to recover more leptons+MET

# What's needed

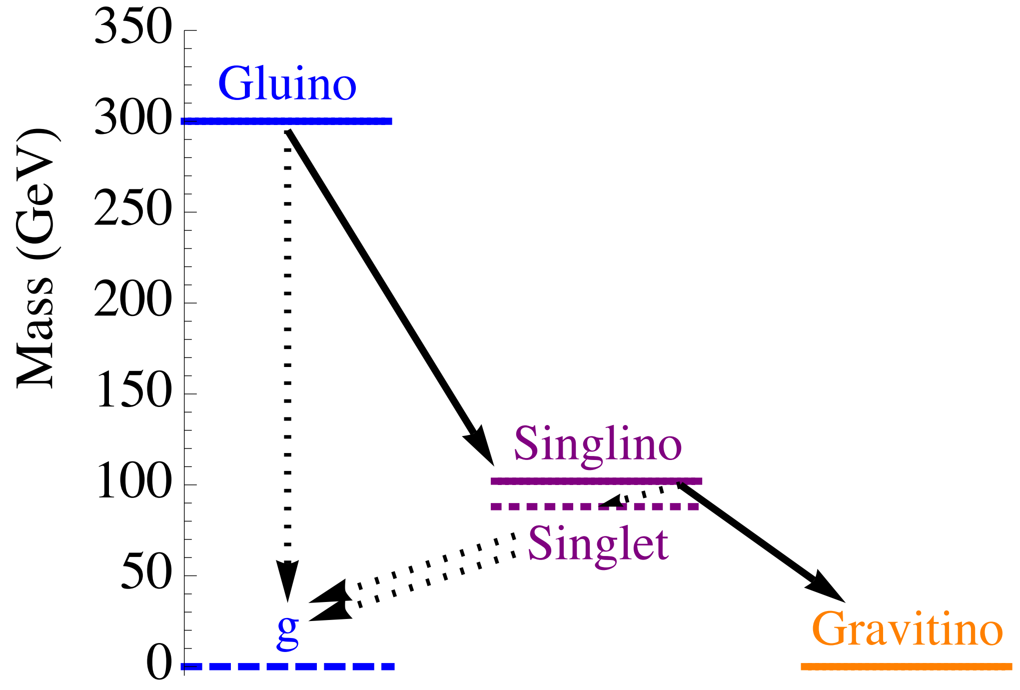
## More topologies or interesting kinematic regimes

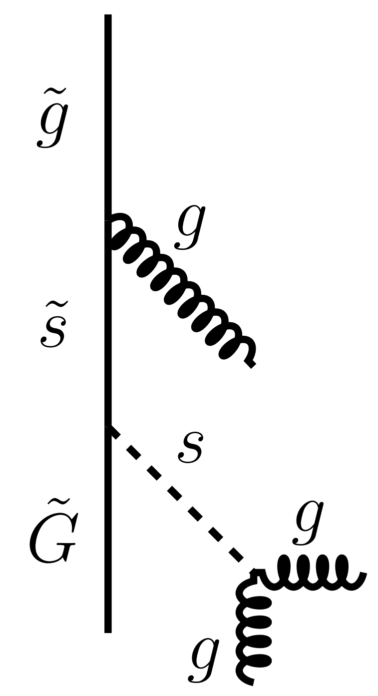
Gluino-Squark-LSP Simplified Model not studied

Stealth Susy

Fan, Reece, Ruderman

Eviscerates MET even with stable LSP



# What's needed

Need a better mapping of signature space

Leptons + Many Jets

Lisanti, Schuster, Strassler, Toro

Many searches require at most 4 or 5 hard jets

But signals can have 6 to 12 hard jets + MET

Many with b-jet

Some of these would fall under "Quantum BHs"

(goes back to SUSY99!)

But how effective are these searches?

# Exciting Times!

We’re rapidly increasing our knowledge of the TeV scale

We don’t have a target to aim at

New physics can be subtle and hidden under backgrounds

Joint Theory-Experiment effort to ensure we’re not letting physics hide